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Vortex Patterns Behind Airfoils in Streamwise Oscillation TA 2307-F1-38

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flow visualization
flow separation
unsteady flow

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Flow Visualization V

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VORTEX PATTERNS BEHIND AIRFOILS IN STREAMWISE OSCILLATION

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We present a limited parametric exploration of vortex patterns generated by airfoils at high angles of attack and executing streamwise oscillations.

1. INTRODUCTION

Streamwise oscillating or "lunging" airfoils have previously been investigated for their lift characteristics /1-4/ with only minor attention given to flow visualization. We therefore focus on a limited parametric exploration of the two-dimensional vortex patterns of lunging airfoils which supplement similar investigations /5-8/ in other separating flow configurations.

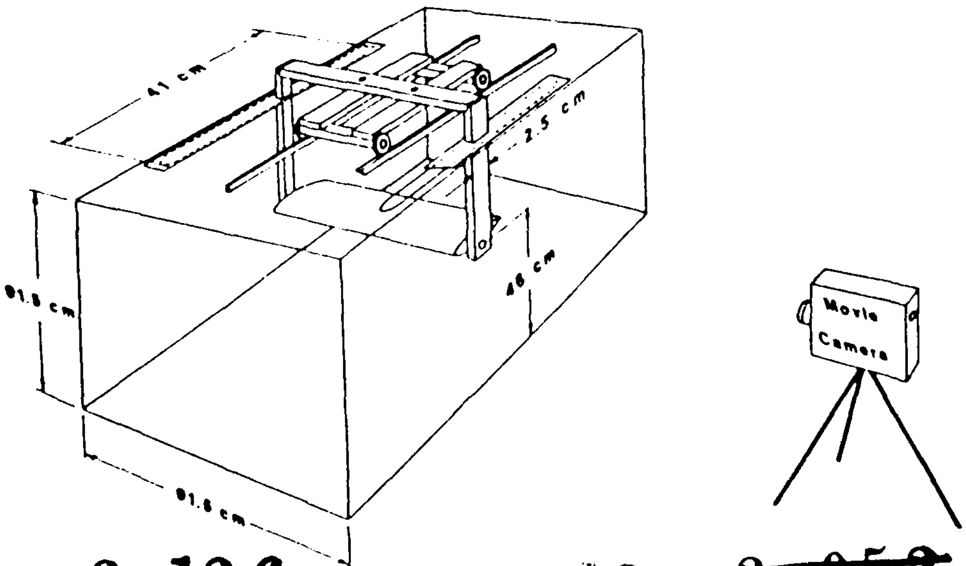

Fig. 1 Three-dimensional sketch of the experimental system.

Relevant dimensionless parameters are the angle of attack α, a reduced frequency $k_h = 2\pi fh/U_o$, a dimensionless amplitude h/c and the Reynolds number $Re = U_o c/\nu$, where f and h are oscillation frequency and amplitude, c is the airfoil chord length, U_o the free stream speed and ν the vimematic viscosity.

2. EXPERIMENTAL SETUP

A NACA 0015 airfoil was suspended from a manually driven cart in the wind tunnel as shown in Fig. 1. The cart allowed streamwise oscillations up to 2 Hz and up to 10 cm amplitude. White fumes of liquid titanium tetrachloride deposited as a center strip on the airfoil made the vortex patterns visible /5/. The patterns were photographed by a movie camera at 64 frames/sec through the front wall of the tunnel. Lighting was by floodlights mounted on the cart.

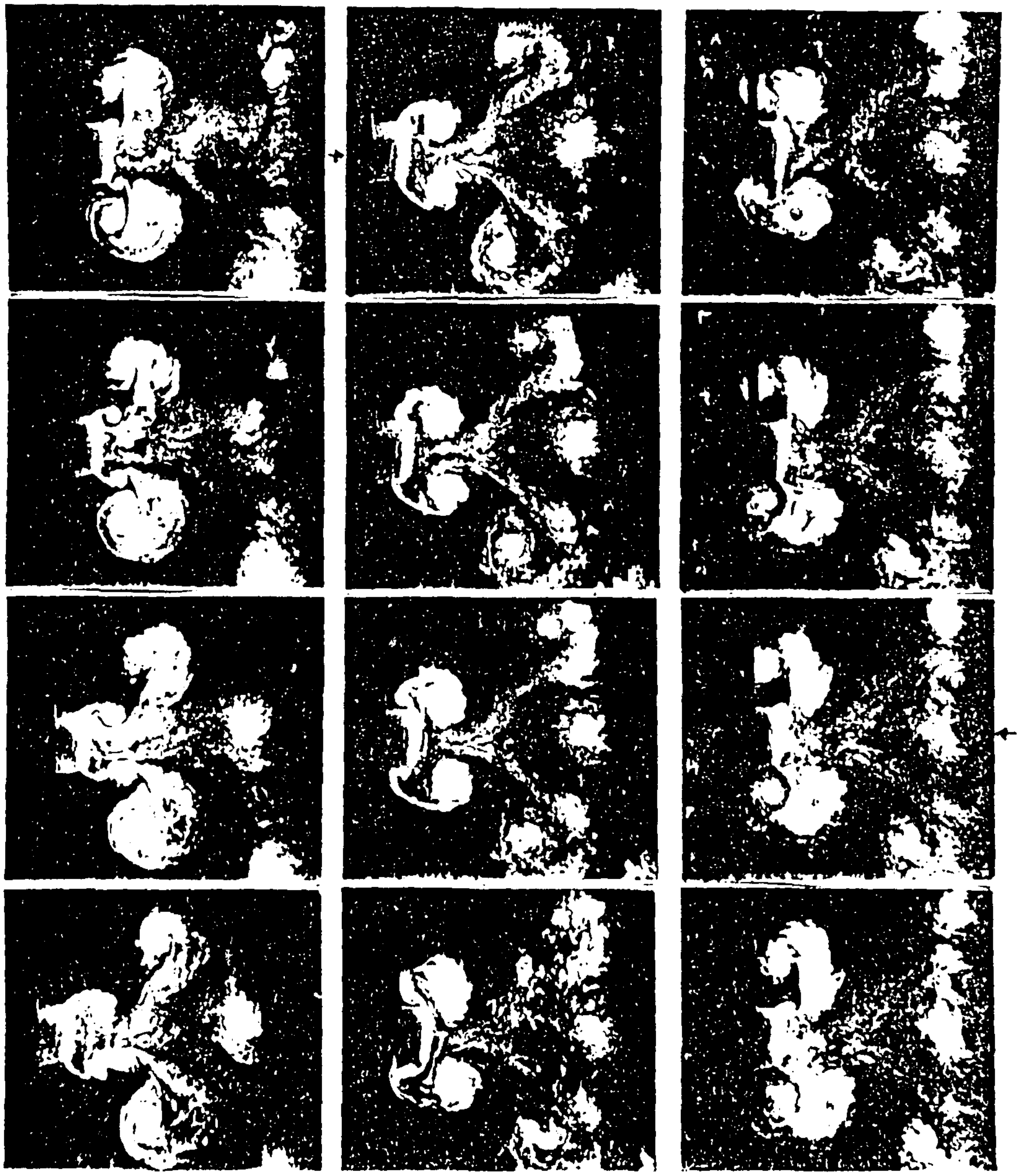

Fig. 2 Sequence for lunging airfoil, $\alpha = 90^\circ$, k_h-0.7, Re=5200, h/c=0.33, Δt-1/16 sec. (c=15.2 cm, h=5.1cm, f-1.33 Hz, U_o-61 cm/sec.).

3. EXPERIMENTAL RESULTS

Fig. 2 presents approximately one period of oscillation at $\alpha = 90^{\circ}$ and f=1.33 Hz, with other data given in the figure caption. Flow is from left to right. Time difference between consecutive frames is $\Delta t = 1/16$ sec. These frames are ordered into columns from top to bottom and across columns from left to right. An arrow pointing right marks the frame where the airfoil has reached its farthest upstream position and starts moving right. A left pointing arrow marks the start of airfoil motion to the left. Smoke diffusion due to turbulence somewhat hampers pattern recognition but basic vortex structures can be recognized.

During one oscillation period, a pair of counter-rotating vortices is generated at the round leading edge and another pair at the sharp trailing edge below it. These vortex pairs traverse into the surrounding irrotational fluid during subsequent oscillation periods. Actually, formation of small, "ornamental" vortices prior to their amalgamation into larger vortices is visible in some frames.

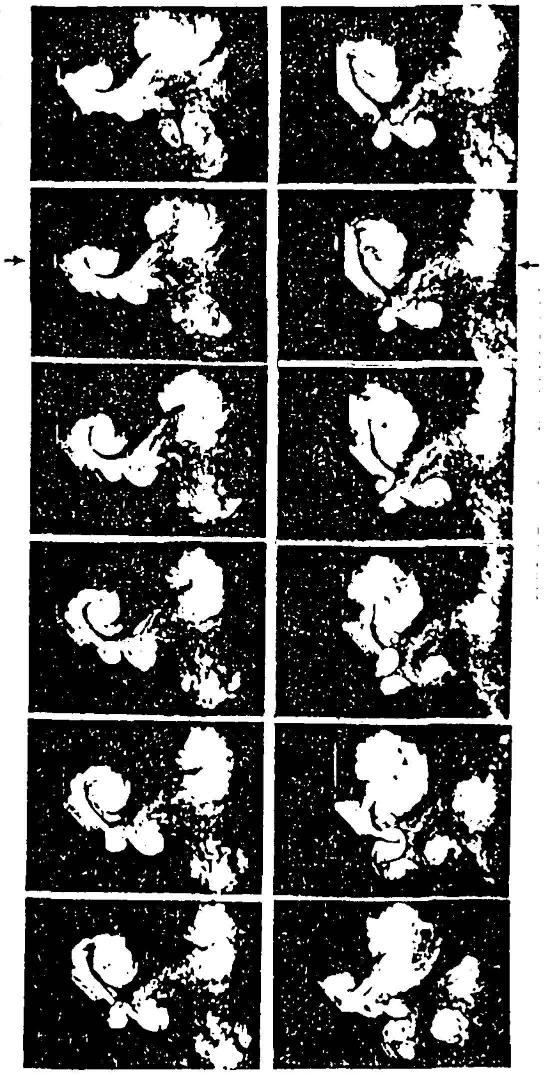

Fig. 3 Sequence for lunging airfoil, $\alpha = 40^{\circ}$, $k = 0.7$, Re=5200, h/c=0.33, $\Delta t = 1/16$ sec. (c=15.2 cm, h=5.1 cm, f=1.33 Hz, $U_o = 61$ cm/sec.).

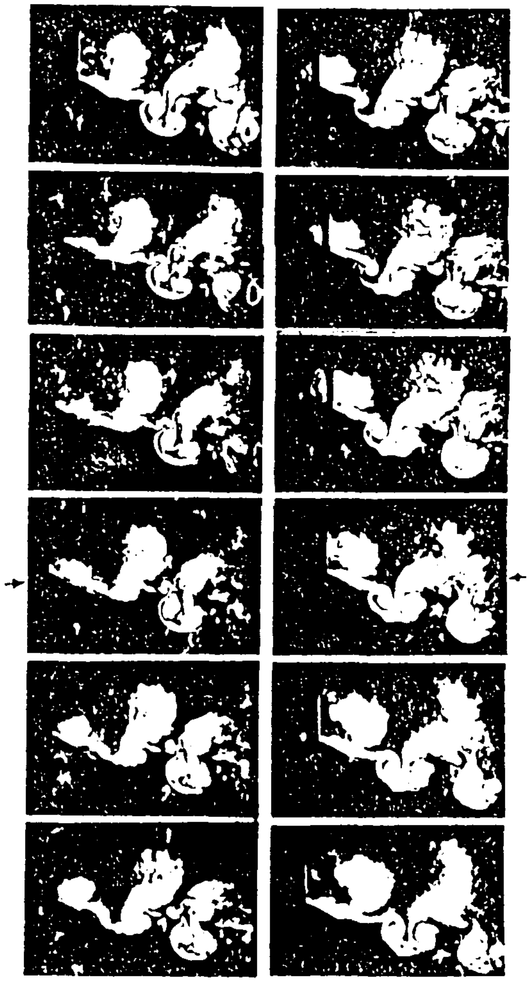

Fig. 4 Sequence for lunging airfoil, $\alpha = 20^{\circ}$, $k_h = 0.7$, Re=5200, h/c=0.33, $\Delta t = 1/16$ sec. (c=15.2cm, h=5.1 cm, f=1.33 Hz, $U_o = 61$ cm/sec.).

Vortex pair formation also occurs at lower angles of attack $\alpha = 40^\circ$ and $\alpha = 20^\circ$ as shown in Figs. 3 and 4. The leading edge vortex pair forms from the dynamic stall vortex during upstream motion of the airfoil and from the counter-rotating secondary vortex. The secondary vortex forms during the backward motion and liftoff of the vortex pair follows. The trailing edge developments are slightly complicated by the occasional shedding of single vortices. Dynamic stall development is sufficiently retarded to give the impression of nearly attached flow during the initial stage of upstream motion of the airfoil.

We also probed dependence of vortex pattern development on reduced frequency. Fig. 5 shows pattern development for $\alpha = 40^\circ$ and a quite low $k_h = 0.26$, with other dimensionless parameters as in Fig. 3. Turbulent diffusion erodes the coherence of vortex patterns even more but it can be discerned that vortex pair formation does not occur. Only clockwise rotating vorticity leaves leading edge. The trailing edge releases only counter clockwise vortices.

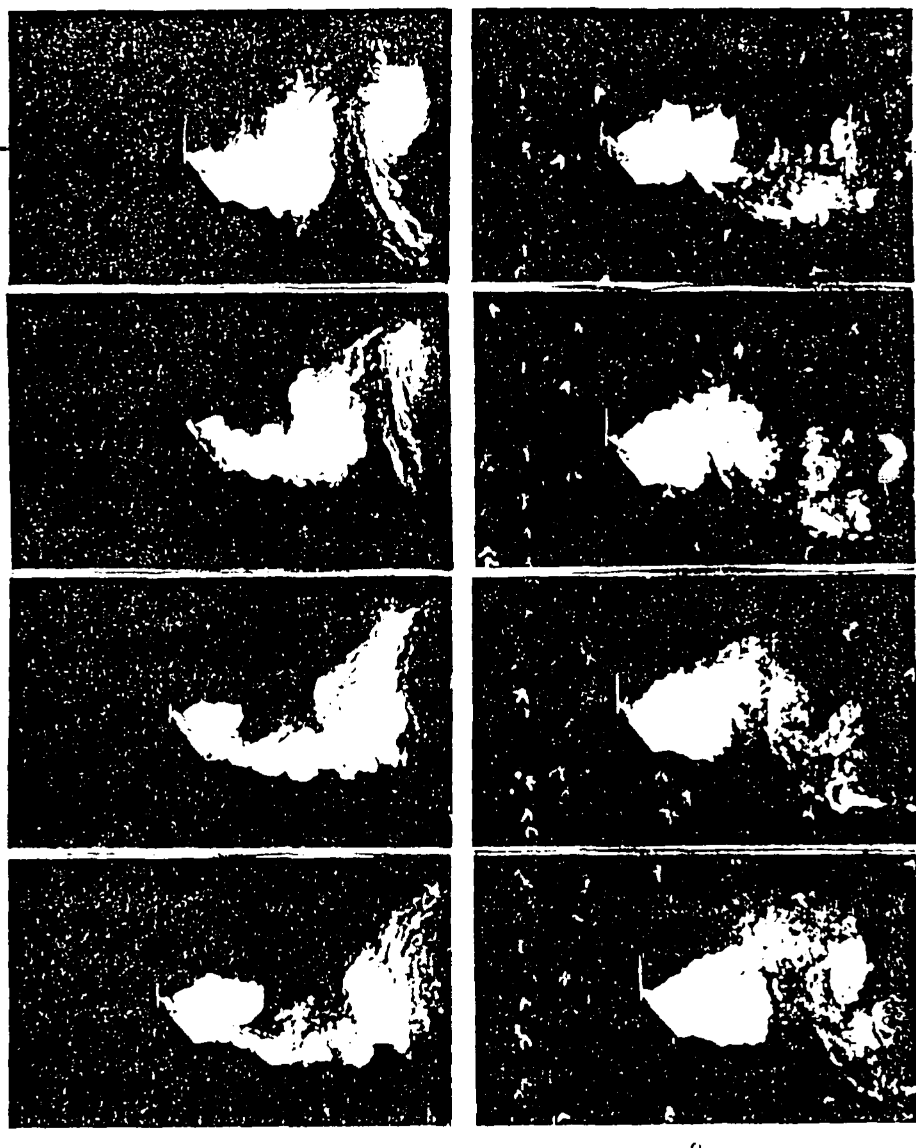

Fig. 5 Sequence for lunging airfoil, $\alpha = 40^\circ$, $k_h = 0.26$, Re = 5200, h/c = 0.33, $\Delta t = 1/4$ sec. (c = 15.2 cm, h = 5.1 cm, f = 0.5 Hz, $U_o = 61$ cm/sec.).

In Fig. 6, we somewhat probe h/c and Re dependence of vortex pattern development, at $\alpha=40^{\circ}$. In this case, h/c has been changed from 0.33 to 1 by going to an airfoil with smaller chord length. This results in Re=1700. Turbulent diffusion is less than in Fig. 5 due to the decrease in Reynolds number and vortex formation is more coherent. In the far wake, h/c should determine the ratio of longitudinal to transversal spacing of the vortices but this highly turbulent regime could not be probed with our apparatus.

When turning the airfoil of Fig. 6 to $\alpha=20^{\circ}$, the natural shedding frequency was not suppressed any more by the airfoil oscillation. In this case, only a modulation of the natural shedding process was recognizable as presented in Fig. 7. Fig. 8 shows the vortex street as it occurred without airfoil oscillation.

4. CONCLUSION

Vortex patterns generated by airfoils in streamwise oscillation can be readily described. Vortex interactions are less complex than in many other configurations described by us.

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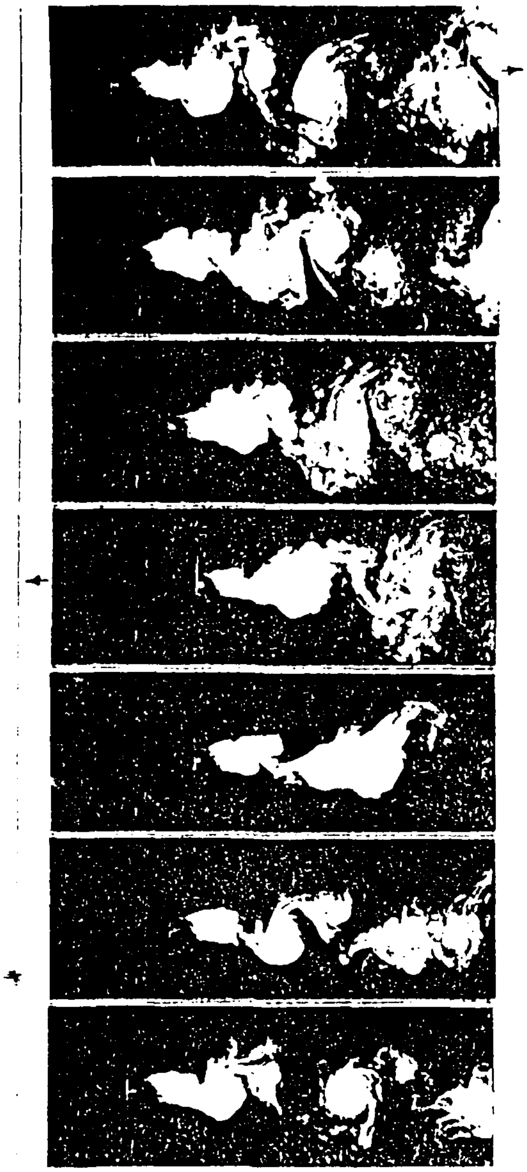

Fig. 6 Sequence for lunging airfoil, $\alpha = 40^{\circ}$, $k_h = 0.26$, Re=1700, h/c=1, $\Delta t = 1/4$ sec. (c=5.1 cm, h=5.1 cm, f=0.5 Hz, U_o=61 cm/sec.).

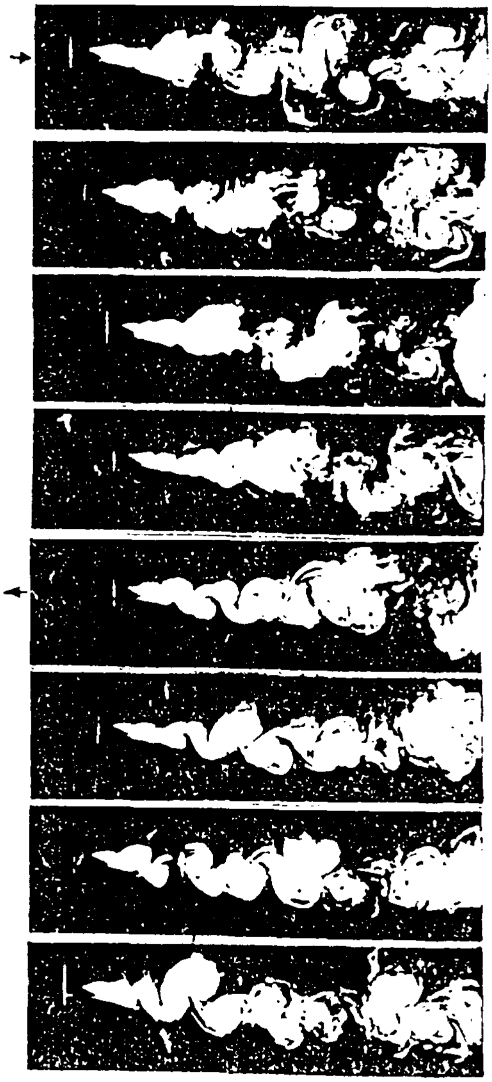

Fig. 7 Sequence for lunging airfoil, $\alpha = 20^{\circ}$, $k_h = 0.13$, Re=1700, h/c=0.5, $\Delta t = 1/4$ sec. (c=5.1 cm, h=2.6 cm, f=0.5 Hz, U_o =61 cm/sec.).

Fig. 8 Airfoil exposed to steady flow, single photograph, $\alpha = 20^{\circ}$, Re=1700, h/c=0 (c=5.1 cm, U_o =61 cm/sec.).